Large Scale Inversion of Basal Stress in Greenland, using Higher Order and Full-Stokes models.

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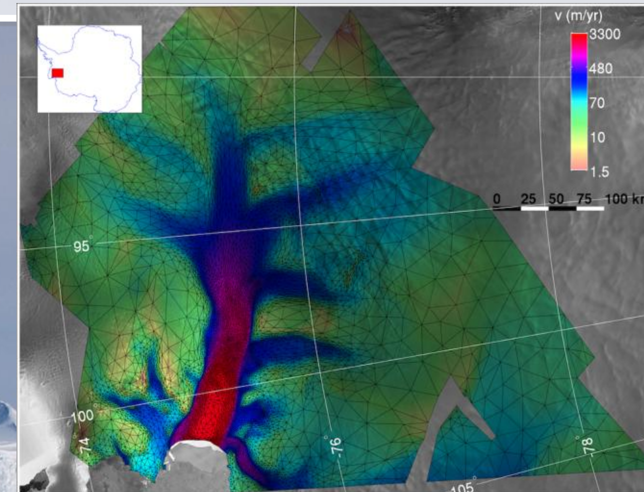
Abstract

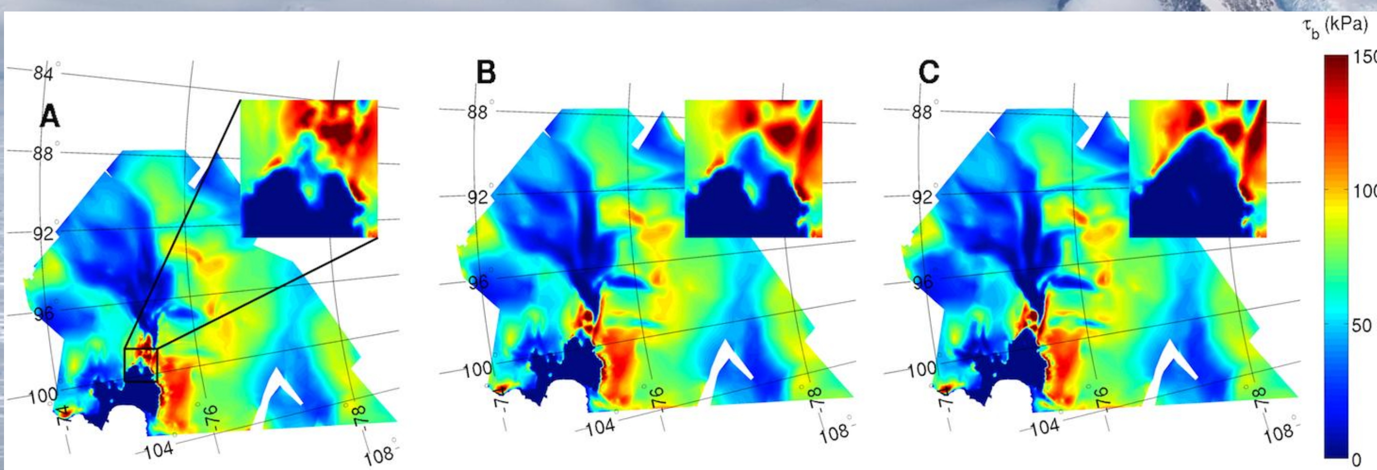
- Abstract: recent developments in data assimilation of InSAR surface velocities to infer basal properties of ice sheets show that there is a strong need for higher order models, including full-Stokes, when bedrock slopes as well as surface velocity are important (Morlighem et al., 2010). On continental ice sheets such as the Greenland ice sheet, this kind of requirement becomes a technical challenge. Here, we present results of inverse control methods in Greenland using InSAR surface velocities, that take advantage of the capabilities for large scale computing in ISSM (Ice Sheet System Model, developed at JPL/UCI).
  We compute basal stress maps using the MacAyeal shelfy-stream, Blatter/Pattyn higher order as well as full-Stokes approximations when necessary. Temperatures are computed using a steady-state assumption at each nonlinear iteration of the data assimilation, in order to avoid having to rely on an initial thermal state which is not adapted to the new distribution of basal shear stress and the corresponding viscous heating. The new basal stress maps are compared for each approximation, and conclusions are drawn on the applicability of each model to basal inversion in Greenland.
  This work was performed at the California Institute of Technology's Jet Propulsion Laboratory under a contract with the National Aeronautics and Space Administration's Modeling, Analysis and Prediction (MAP) Program.

- Where 3D effects are pronounced, Full-Stokes modeling should be investigated .
- Morlighem et al ,2010 showed that in the vicinity of the Pine Island Glacier grounding line, the sharply rising bed exerts a backpressure on the flow. This effect is only captured by 3D Full-Stokes model.
- We need to investigate need for FS models further, at the continental scale.



Velocity and finite element mesh of Pine Island Glacier

Inferred basal drag (kPa) for three ice flow models



2D SSA	3D BP	FS

Reference:

Morlighem, M., E. Rignot, H. Seroussi, E. Larour, H. Ben Dhia, and D. Aubry (2010),
Spatial patterns of basal drag inferred using control methods from a full-Stokes and simpler models for Pine Island Glacier, West Antarctica,
Geophys. Res. Lett., 37, L14502, doi:10.1029/2010GL043853.

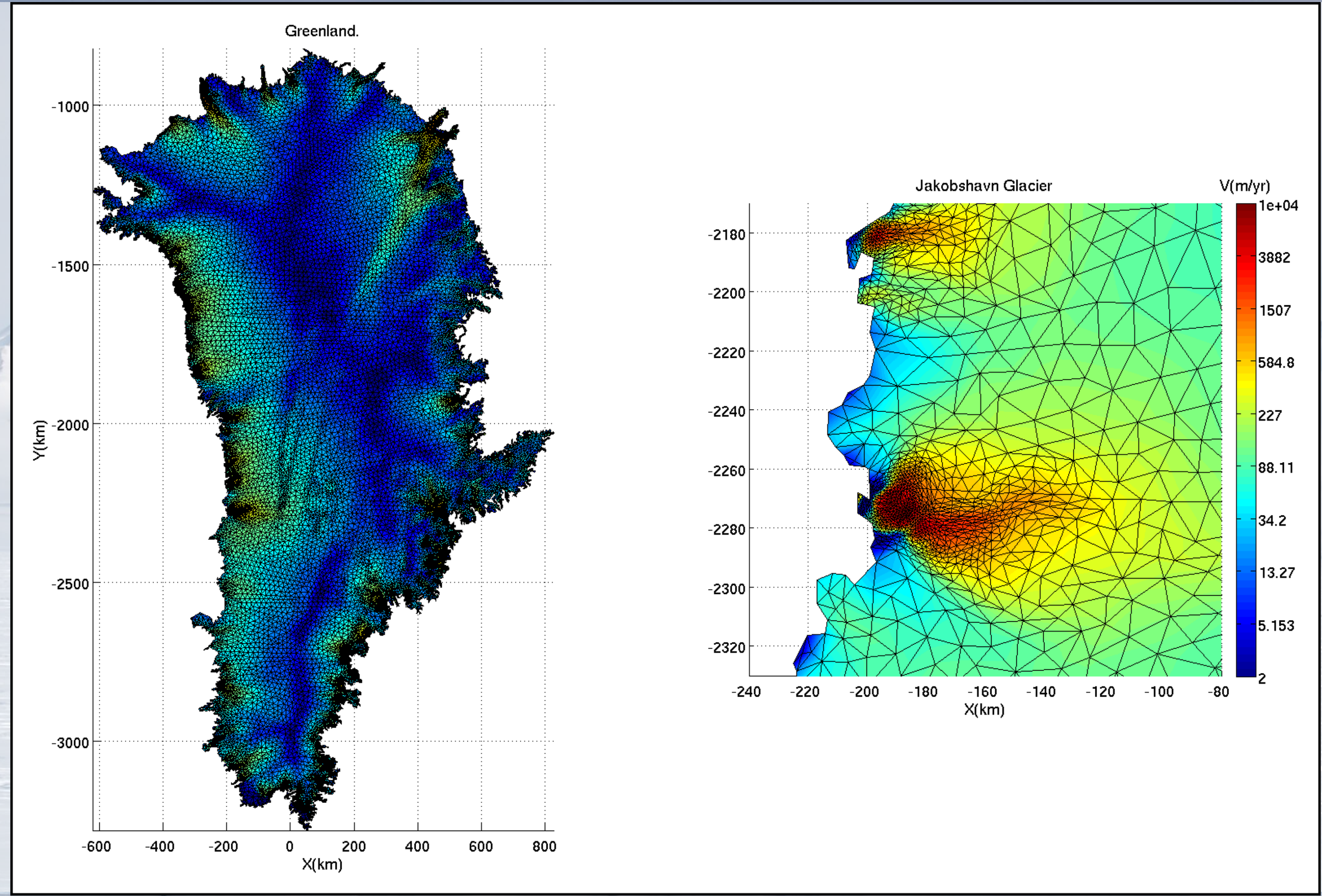
http://www.agu.org/pubs/crossref/2010/2010GL043853.shtml

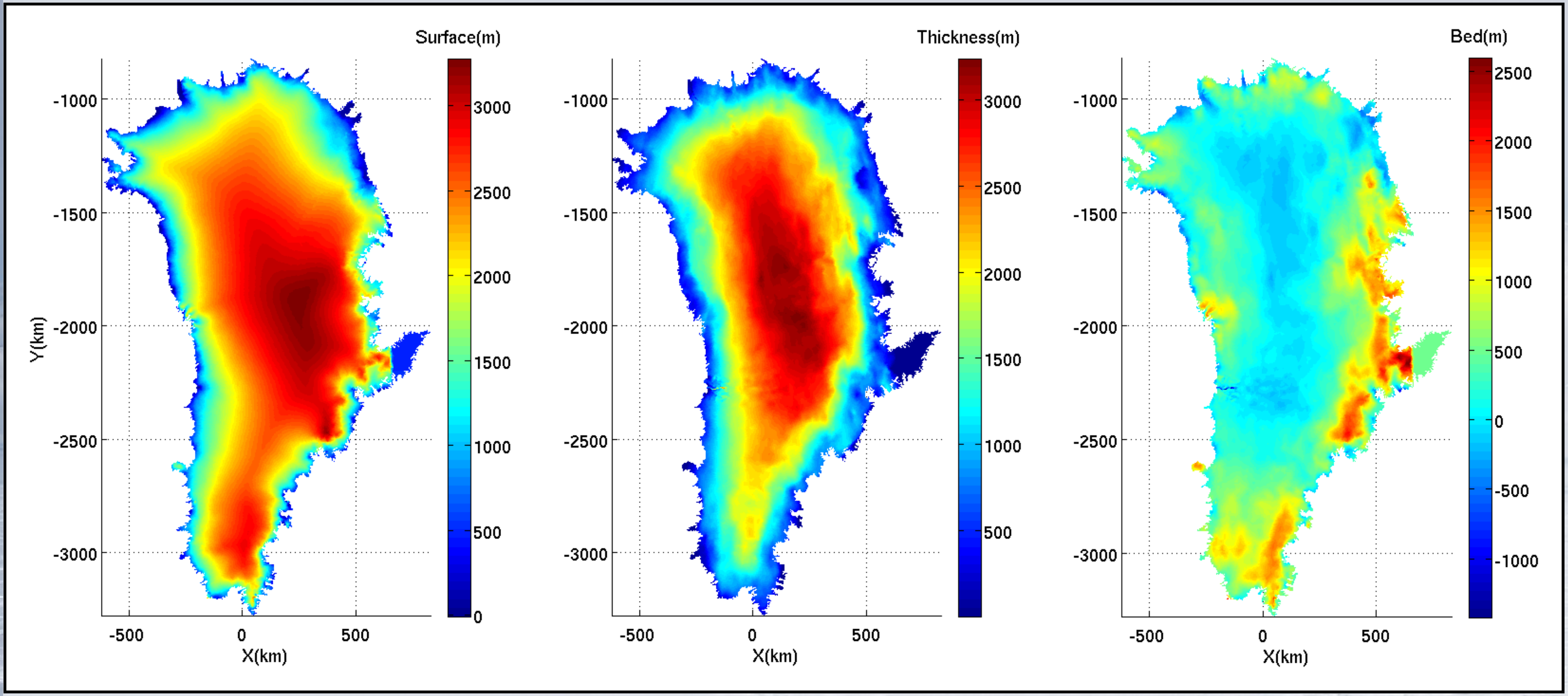
Neglect horizontal gradient bridging effects/hydrostatic assumption.

Shelfy-Stream Approximation

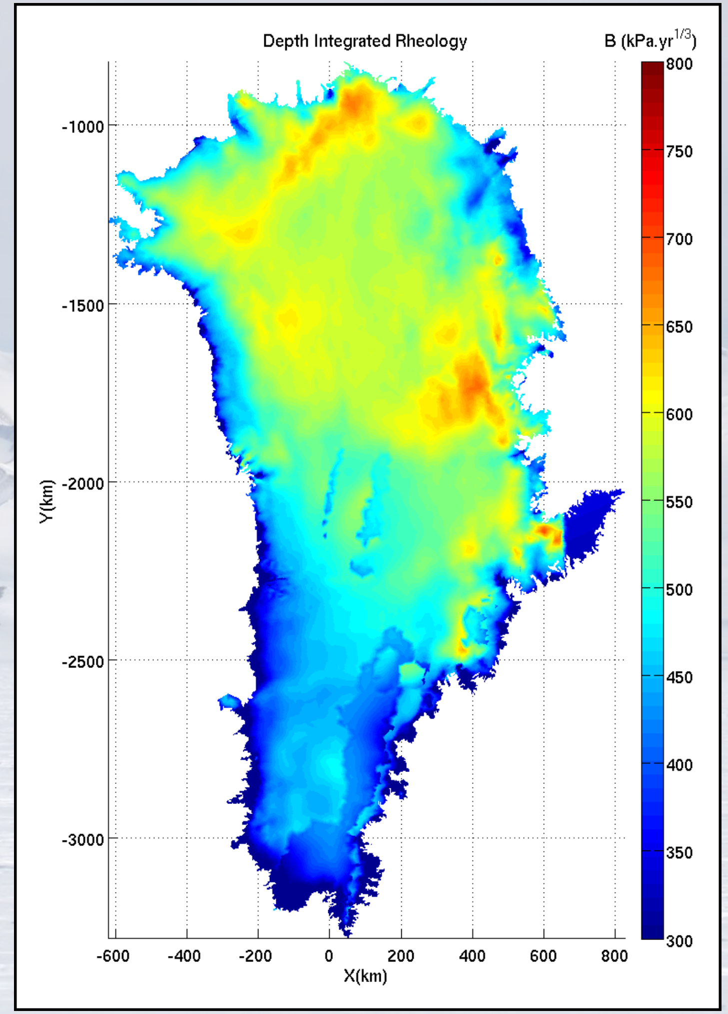
$$\begin{cases} \frac{\partial}{\partial x}\left(2\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}+\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial u}{\partial z}+\mu\frac{\partial w}{\partial x}\right)-\frac{\partial P}{\partial x}=0\\ \frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial y}+\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(2\mu\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial v}{\partial z}+\mu\frac{\partial w}{\partial y}\right)-\frac{\partial P}{\partial y}=0\\ \frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial z}+\mu\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial z}+\mu\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial z}\left(2\mu\frac{\partial w}{\partial z}\right)-\frac{\partial P}{\partial z}-\rho g=0\\ \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \end{cases}$$

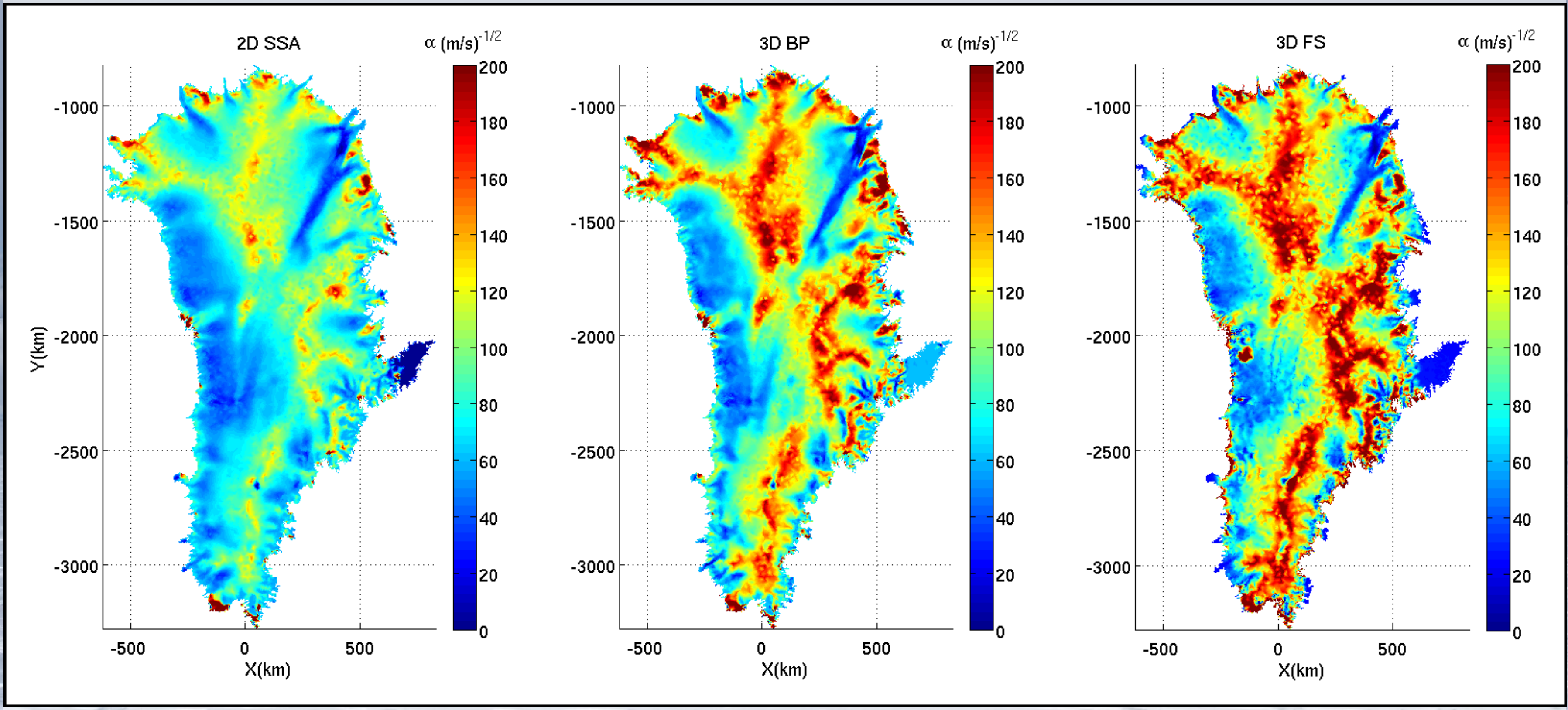
Neglect bridging effects/hydrostatic assumption.


Greenland.
Y(km)
X(km)
-1000
-1500
-2000
-2500
-3000
-600
-400
-200
0
200
400
600
800
Jakobshavn Glacier
V(m/yr)
-2180
-2200
-2220
-2240
-2260
-2280
-2300
-2320
-240
-220
-200
-180
-160
-140
-120
-100
-80
X(km)
1e+04
3882
1507
584.8
227
88.11
34.2
13.27
5.153
2

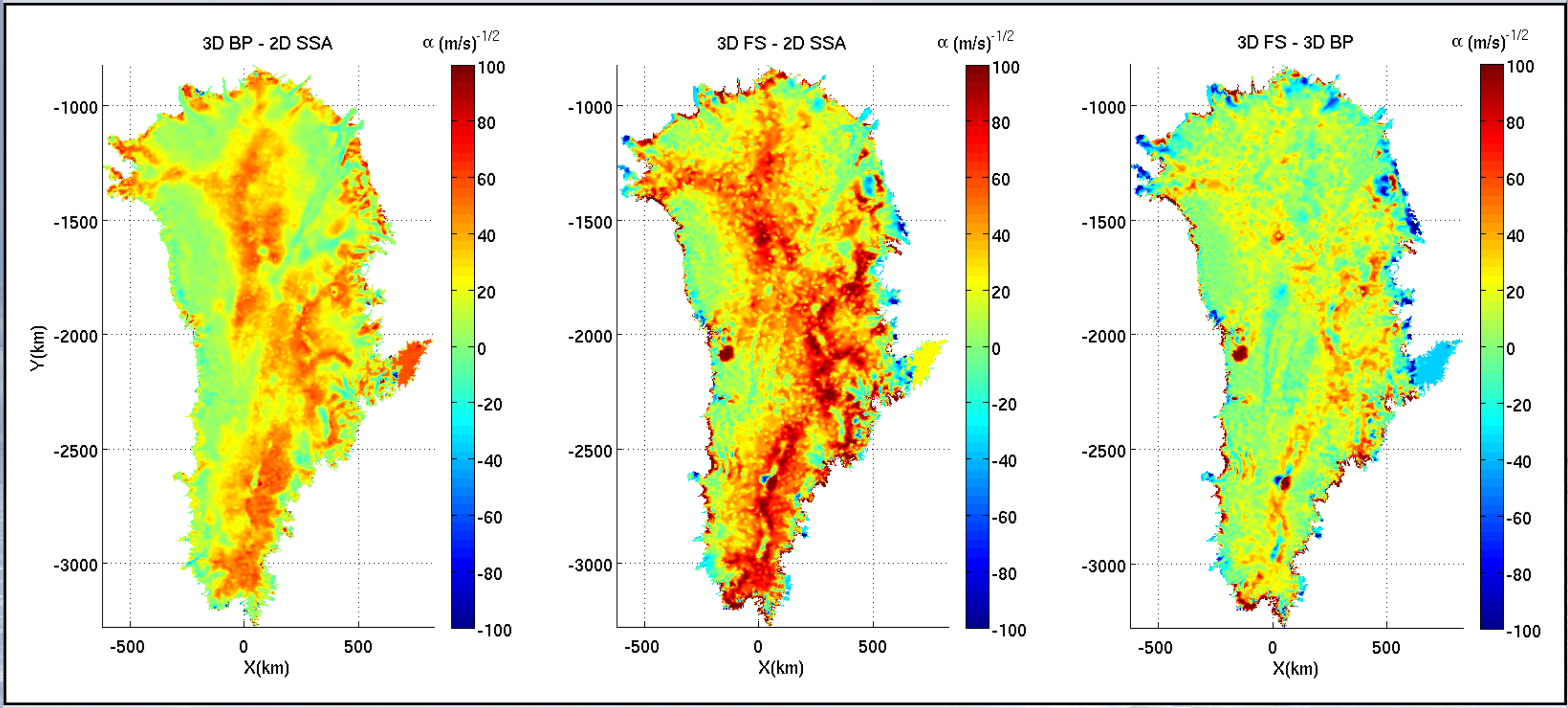


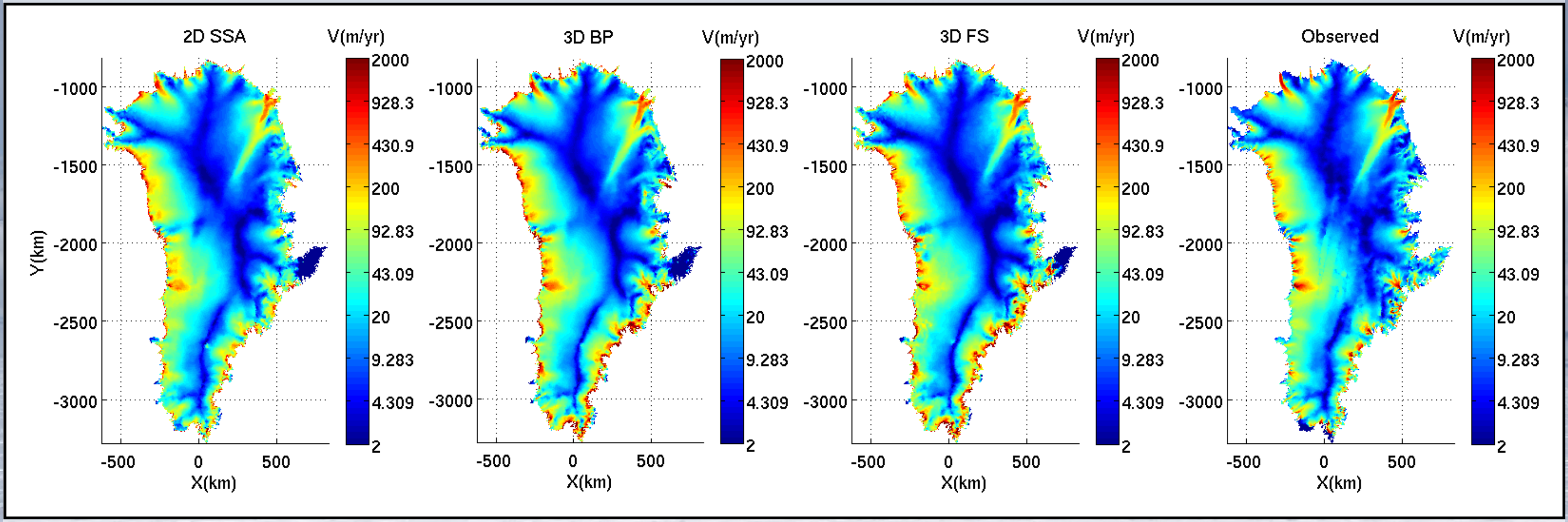
Surface(m)
Thickness(m)
Bed(m)
Y(km)
X(km)
X(km)
X(km)
-1000
-1500
-2000
-2500
-3000
-500
0
500
3000
2500
2000
1500
1000
500
0
-500
-1000

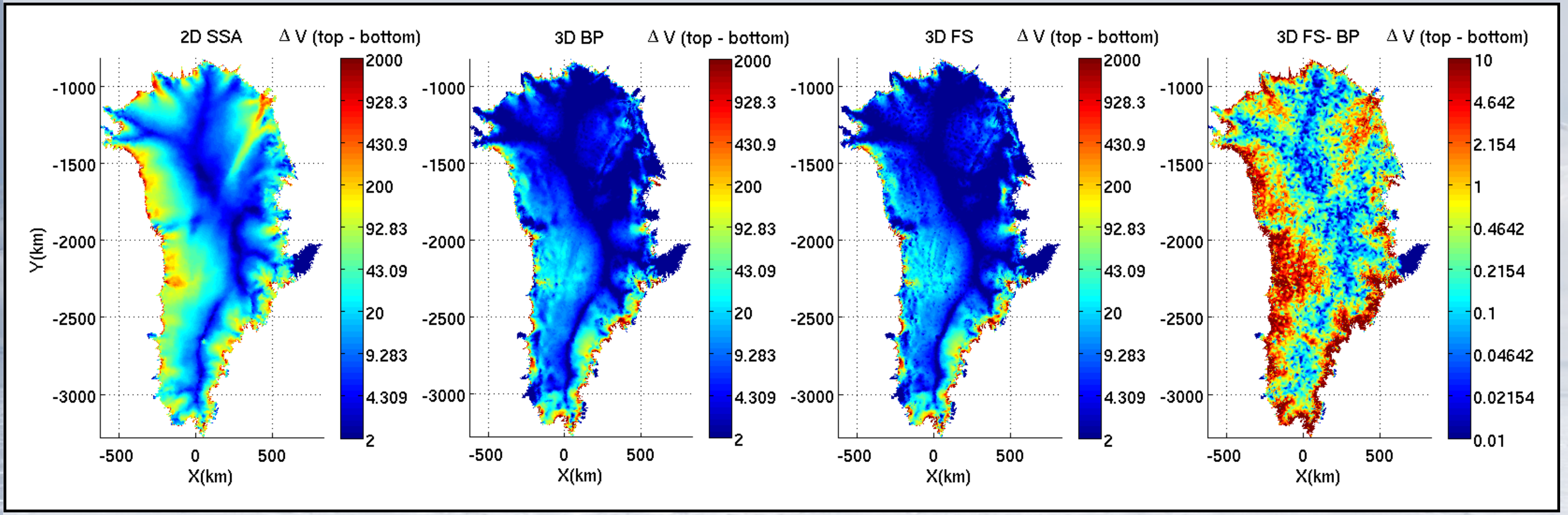

Depth Integrated Rheology
B (kPa.yr$^{1/3}$)
800
750
700
650
600
550
500
450
400
350
300
-1000
-1500
-2000
-2500
-3000
Y(km)
-600
-400
-200
0
200
400
600
800
X(km)



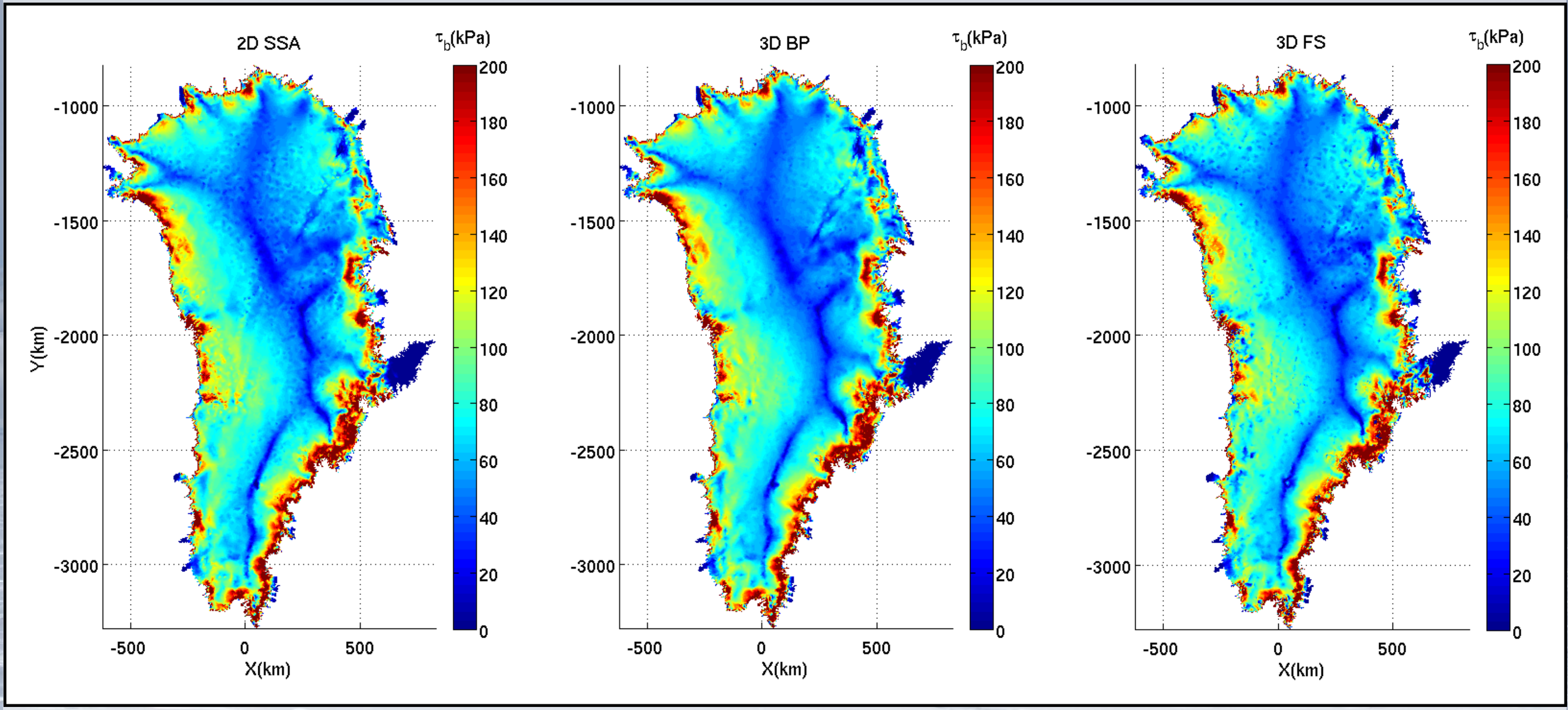
2D SSA
3D BP
3D FS
α (m/s)^-1/2
Y(km)
X(km)
-1000
-1500
-2000
-2500
-3000
-500
0
500
200
180
160
140
120
100
80
60
40
20
0

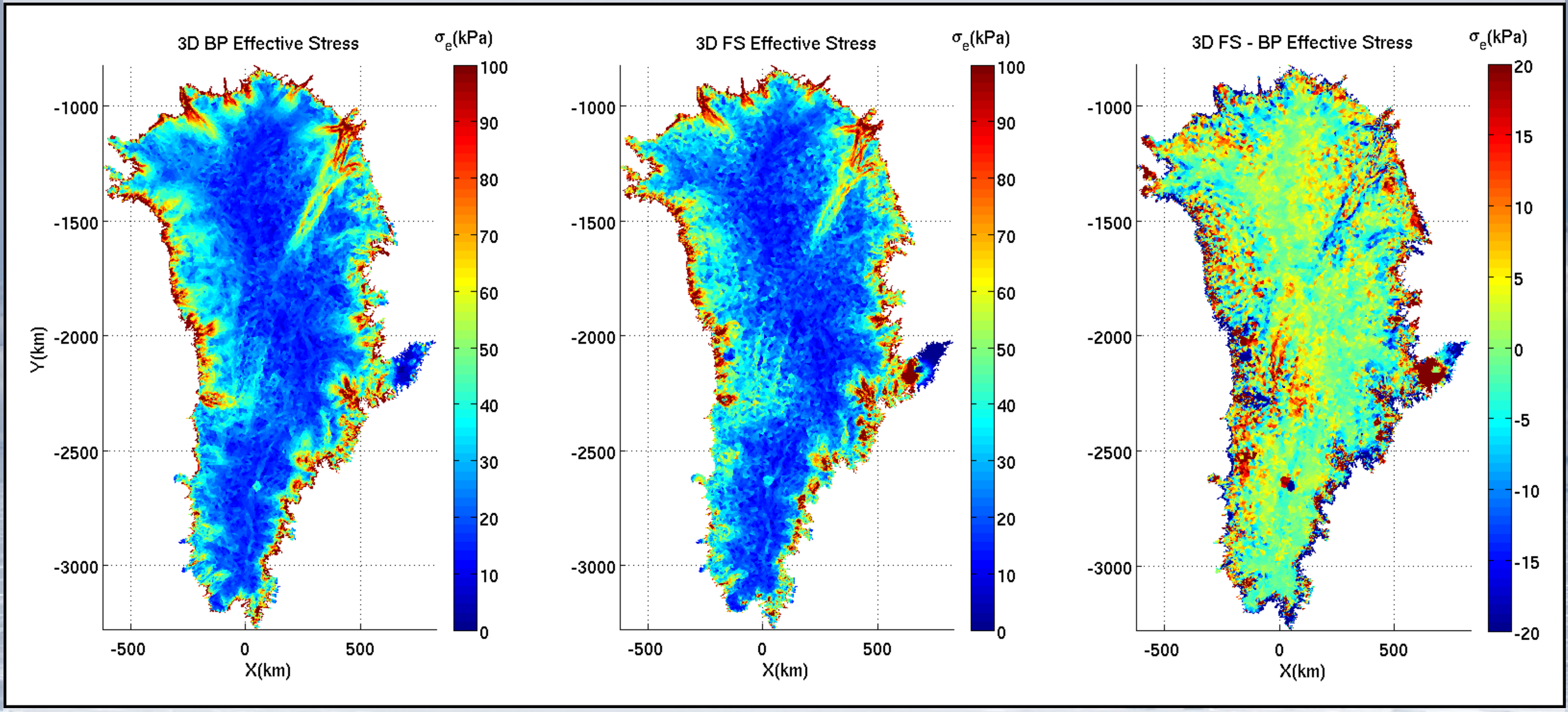

3D BP - 2D SSA
α (m/s)-1/2
3D FS - 2D SSA
α (m/s)-1/2
3D FS - 3D BP
α (m/s)-1/2
Y(km)
X(km)
-1000
-1500
-2000
-2500
-3000
-500
0
500
100
80
60
40
20
0
-20
-40
-60
-80
-100

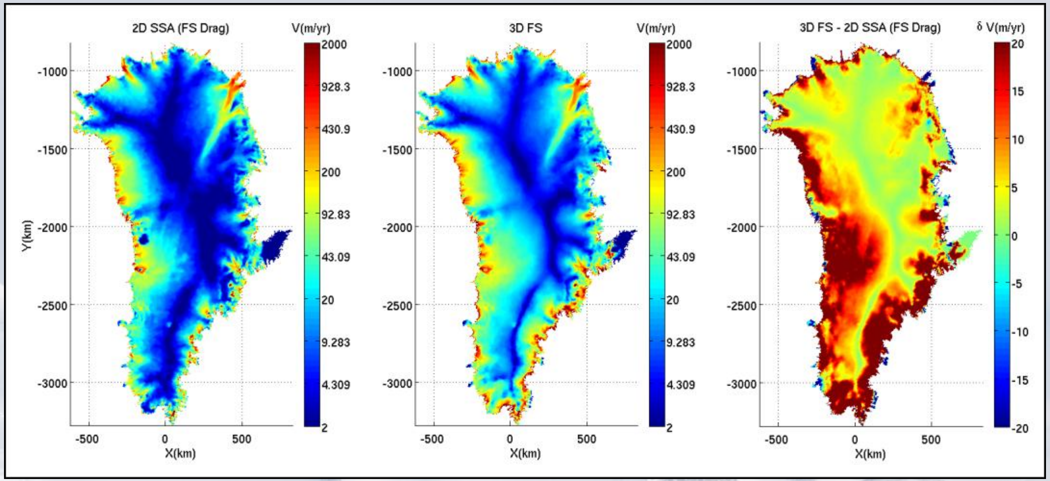

2D SSA
V(m/yr)
3D BP
V(m/yr)
3D FS
V(m/yr)
Observed
V(m/yr)
2000
928.3
430.9
200
92.83
43.09
20
9.283
4.309
2
-1000
-1500
-2000
-2500
-3000
Y(km)
-500
0
500
X(km)



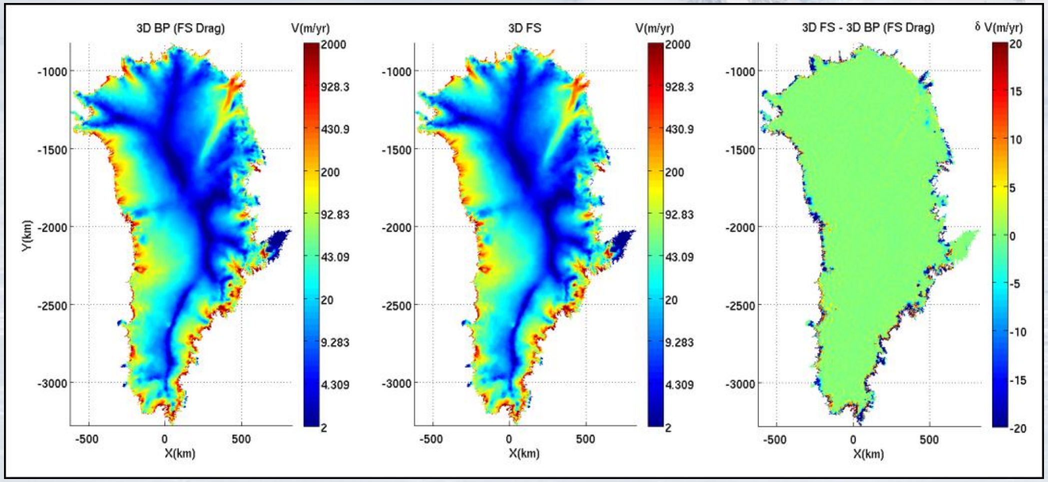
2D SSA
Δ V (top - bottom)
3D BP
Δ V (top - bottom)
3D FS
Δ V (top - bottom)
3D FS- BP
Δ V (top - bottom)
Y(km)
X(km)
-1000
-1500
-2000
-2500
-3000
-500
0
500
2000
928.3
430.9
200
92.83
43.09
20
9.283
4.309
2
10
4.642
2.154
1
0.4642
0.2154
0.1
0.04642
0.02154
0.01


2D SSA
3D BP
3D FS
τ_b(kPa)
Y(km)
X(km)
-1000
-1500
-2000
-2500
-3000
-500
0
500
200
180
160
140
120
100
80
60
40
20
0


3D BP Effective Stress
3D FS Effective Stress
3D FS - BP Effective Stress
σ_e(kPa)
Y(km)
X(km)
-1000
-1500
-2000
-2500
-3000
-500
0
500
100
90
80
70
60
50
40
30
20
10
0
20
15
10
5
0
-5
-10
-15
-20



2D SSA (FS Drag)
3D FS
3D FS - 2D SSA (FS Drag)
V(m/yr)
δ V(m/yr)
Y(km)
X(km)



3D BP (FS Drag)
3D FS
3D FS - 3D BP (FS Drag)
V(m/yr)
δ V(m/yr)
Y(km)
X(km)

Thanks !

Special thanks to:

Ian Joughin for providing the InSAR surface velocity map of Greenland.

This work was performed at the California Institute of Technology's Jet Propulsion Laboratory under a contract with the National Aeronautics and Space Administration's Cryosphere Science Program.